AD 295 127

RADIATION ENVIRONMENT FOR MANNED SPACECRAFT

S. H. Dole

P-2691

RADIATION ENVIRONMENT FOR MANNED SPACECRAFT

S. H. Dole*

The RAND Corporation, Santa Monica, California

Just about three years ago workers in the various fields related to manned space flight generally began to become aware of the hazards to men in space resulting from large solar flares, and this soon became their number one concern. Since that time, hundreds of scientific papers have been written about the various kinds of radiation and high-energy particles that are encountered by space probes or will be encountered by the crews of manned spacecraft. A number of excellent reviews are now available.[1,2] Many different opinions have been expressed as to the technical difficulties presented by one or another of the kinds of radiation, and estimates of shielding requirements have varied widely. However it is always emphasized that, although much is now known about the radiation environment in space, there is still much we do not know. Thus whatever is said must be regarded as tentative and qualified by the statement that we still do not know all the answers.

In the present review of the current state of knowledge about the radiation environment, the various kinds of radiation in space will be treated from the viewpoint of their significance to different kinds of space missions, here classified as: Low earth orbits, High earth orbits, Lunar missions and Interplanetary missions. These are differentiated from one another by characteristic differences in the radiation environment and also in the choice of tactics available for the avoidance of extreme levels of radiation.

---

*Any views expressed in this paper are those of the author. They should not be interpreted as reflecting the views of The RAND Corporation or the official opinion or policy of any of its governmental or private research sponsors. Papers are reproduced by The RAND Corporation as a courtesy to members of its staff.

This paper was prepared for presentation at a meeting of the Institute of Environmental Sciences, Hotel Statler, Los Angeles, California, April 18, 1963.

Before taking a detailed look at the specific kinds of space missions, these are the kinds of radiation that will be treated: electromagnetic radiation from the sun including ultraviolet light, visible light and infrared light; the so-called Van Allen belt radiation, or electrons and protons trapped in the earth's magnetic field; high-energy protons originating spasmodically in large solar flares; and cosmic particles of galatic origin.

ELECTROMAGNETIC RADIATION FROM THE SUN

In free space, the skin of a space vehicle receives sunlight completely unfiltered. Consequently, as compared with an object in sunshine on the surface of the earth at sea level, the object in space is exposed to much higher levels of ultraviolet radiation, somewhat higher levels of infrared and slightly high levels of visible light. However since it is inconceivable that a human being would ever intentionally expose himself to direct sunlight in space, there is not too much hazard from ultraviolet. Most glasses and other transparent materials are almost opaque to ultraviolet so there is little danger of sunburn. Care must be exercised to avoid exposing the eyes to direct or reflected sunlight, but this should not constitute too grave a problem as we are protected by the blink reflex and instinctively refrain from looking right at the sun.

The visible and infrared radiation from the sun produce radiant heating of any exposed surfaces. An illustration of this: at the earth's distance from the sun a black plate exposed to direct sunlight would reach an equilibrium temperature of 250° F, a white surface would reach an equilibrium temperature of -60° F, while a polished nickel surface would reach 650° F.[3] By proper choice of skin materials, their color or absorptivity and emissivity, temperatures can be held within the comfortable range.

VAN ALLEN BELTS

The Van Allen belts exist as a consequence of the fact that the earth has a magnetic field--and consist of protons and electrons that have been trapped in this field. The most intense part of the Van Allen belt is located directly over the earth's magnetic equator at an altitude of about 2000 miles. The high energy protons and the high energy electrons in the Van Allen belts can give significant radiation doses to the crews of spacecraft but the dose rates could be kept to acceptably low levels through the use of fairly massive shielding. (Electromagnetic shielding is being studied also, and in some quarters, it is felt that this may turn out to be superior to shielding by the mere interposition of mass.) Because the intense parts of the Van Allen belts are fairly well localized in space, manned spacecraft on lunar or interplanetary missions can avoid passing through the more intense regions; in any event, spacecraft on such missions will normally pass through them rapidly so the dosages due to trapped particles will be less important than those due to other phenomena.

SOLAR FLARE PROTONS

These constitute the most serious radiation hazard of space flight. From time to time the sun emits great bursts of high energy protons and these could give incapacitating or lethal doses of radiation to crews in inadequately shielded spacecraft. Such large fluxes of protons do not occur very often but, since we cannot now predict when large flares will occur, spacecraft, particularly those on prolonged missions, will have to be prepared to shield themselves against large flares. The sun is continually sending out small bursts of protons and these are fairly easy to shield against as they can be stopped by the ordinary structure of the spacecraft. Larger flares occur less frequently, and the really big, dangerous flares are quite infrequent. Unfortunately we do not yet have enough data on the frequency of occurrence as a function of total proton flux to enable one to make an accurate prediction of the probabilities that a damaging flare will or will not occur during a given period of time. In general, large flares are associated with large sunspots and the flare frequency is correlated with the sunspot frequency so that the flare hazard more or less follows the eleven-year sunspot cycle. However, the correlation is not good enough for predictive purposes because some of the biggest solar flares have occurred halfway between sunspot maximum and sunspot minimum.

GALACTIC COSMIC PARTICLES

These are the most highly energetic particles known, stripped nuclei of atoms moving at speeds approaching the speed of light. Fortunately the flux of galactic cosmic particles is very low and the very massive, highly energetic particles constitute only a small percentage of the total flux. Although the very energetic particles have enormous penetrating power and would be difficult to shield against, the total body dosage due to cosmic particles may be of the order of only 0.05 to 0.1 rem per day or less, probably too small to be significant as a total body dose. However, the cosmic particles apparently are capable of killing individual body cells when they score a direct hit on a cell nucleus. This is not very important with respect to most body cells since they are constantly being eliminated and replaced anyway--but it may be important with respect to the nervous system. Nerve cells are not replaced when they are lost so two questions must be answered with respect to the loss of nerve cells due to destruction by primary cosmic particles. What will be the loss rate? and, How many nerve cells can one lose before undesirable effects begin to appear? Neither question can be answered definitely at present. However on the basis of present estimates, serious biological effects will probably not become manifest without very extended exposure times.(4)

Now having very briefly summarized the principal types of natural radiation of importance to manned spacecraft, let us consider these with respect to various kinds of space missions.

LOW EARTH ORBITS (Altitudes of 100 to 300 miles, that is, above the denser part of the earth's atmosphere but below the significant effects of the Van Allen belts)

Spacecraft in low earth orbits that are not highly inclined to the equator are very well protected from solar flare protons by the earth's magnetic field. Consequently spacecraft on these orbits do not require any special shielding beyond that needed for thermal regulation and that provided by the normal spacecraft structure. The thermal regulation problem is somewhat more complicated for a close-in satellite than for a spacecraft well away from the earth since it spends about half the time in the earth's shadow.

Low earth orbiters on highly inclined orbits (on inclinations greater than about 60°) lose the protection of the earth's magnetic field when on the part of the orbit that crosses the auroral zones of the earth. Satellites of this class that are designed to be in orbit for a long time will probably have to be equipped with flare shelters to provide protection in the event of the occurrence of a large proton-producing flare just as the satellite is crossing the north or south polar regions. Flare shelters are conceived of as being small, heavily shielded compartments into which the crew can crawl when they are warned of a potentially dangerous flare. Carbon (graphite) shields having a thickness of possibly 2 to 5 inches may be needed to reduce the biological dosages to acceptable levels. On the other hand, low altitude spacecraft might also be able to alter their inclinations to avoid crossing the auroral zones while a large flare was in progress, or could easily abort the mission and return to earth.

<u>HIGH EARTH ORBITS</u> (Altitudes of 300 to possibly 40,000 miles)

Spacecraft orbits imbedded within the Van Allen belt or crossing it, if on inclined orbits, will be exposed steadily or intermittently to significant fluxes of high energy protons or electrons or both. There are some indications that it may not be practicable to shield against the high energy protons of the heart of the inner Van Allen belt on a long term basis since extremely heavy shielding would be needed, possibly three or four feet of carbon. The electrons of the outer belt are more easily shielded against. A composite shield made up of a thin skin of a light metal to stop the electrons and an inner shield made of a sheet of lead to absorb the secondary x-rays produced when electrons hit the outer skin might provide reasonable protection in the outer zone. Much would depend on the expected duration of the mission, its exact orbital parameters, and what is considered a tolerable dose rate and a total accumulated dose for the mission. A distant earth satellite would also need to carry a flare shelter to provide refuge from solar flares. Beyond the Van Allen belts an earth satellite may be regarded as being in free space as far as the radiation environment is concerned.

LUNAR MISSIONS

The radiation environment of a lunar mission will depend on the specific mission details, the length of the time in space, whether a landing is to be made, whether permanent bases on the moon are available at the time, etc. If the time where the lunar mission takes off can be selected with care, then it will be possible to reduce the hazard of solar flares since a typical lunar transit takes about two and half days and it is possible to select in advance periods of time that will be free of solar flares for about five days.

If the take-off cannot wait for a predicted flare-free period then flare shelters must be provided, although the probabilities are quite small that a large solar flare will occur within a given two to five day period of time.

INTERPLANETARY MISSIONS

For long missions, lasting several hundred days, the solar flare problem becomes the dominant one, and a flare shelter for the crew will be a necessity, since the probability that large solar flares will occur increases as the length of the mission increases. Graphite shields having a thickness of several inches may be adequate to give protection against the largest solar flares that have been observed to date--but again it should be emphasized that there are serious gaps in present day knowledge of many solar phenomena, and it will probably be wise to provide shielding fairly generously in early interplanetary expeditions to make up for deficiencies in our knowledge.

REFERENCES

1. Foelsche, Trutz, Current Estimates of Radiation Doses in Space, NASA TN D-1267, July 1962.

2. American Machine and Foundry Company, Space Radiation Guide, AMRL-TDR-62-86, Air Force Systems Command, W-P AFB, August 1962.

3. Buettner, Konrad, "Bioclimatology of Manned Rocket Flight", in Space Medicine, ed. J. P. Marbarger, U. of Ill. Press, Urbana, Ill., 1951.

4. Tamplin, A. R., and H. K. Fisher, Galactic Cosmic Radiation and Manned Space Flight, Research Memorandum RM-3043-PR, The RAND Corporation, December 1962.